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DEVISING A METHODOLOGY FOR ESTIMATING THE ECONOMIC EFFICIENCY OF MANAGING POWER ENTERPRISES' INFORMATION POTENTIAL UNDER THE CONDITIONS OF DIGITAL COHERENCE

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This study investigates the process that assesses the economic efficiency of implementing an investment project aimed at managing the information potential of energy enterprises, taking into account digital coherence factors.

The task addressed relates to the lack of a holistic methodology that could make it possible to quantitatively assess the economic efficiency of managing the information potential of energy enterprises, taking into account the level of digital coherence.

A methodology for assessing the economic efficiency of managing the information potential of energy enterprises in the context of digital coherence has been devised and substantiated. The methodology was considered as an integrated tool for diagnosing, analyzing, and predicting the effectiveness of management decisions based on the consistency of digital, analytical, organizational, and strategic components of the enterprise.

The methodology makes it possible to assess the economic efficiency of using information potential, taking into account digital coherence, identifying imbalances in the digital architecture, and justifying management decisions regarding the optimization of digital resources and transformations in the energy sector.

A system of quantitative criteria and indicators has been formed to assess the economic efficiency of information potential management of energy enterprises, which reflects the level of digital coherence and allows for an objective analysis of the results of digital transformation.

The methodology has been tested using an example of Zaporizhzhia Power Plant, which made it possible to trace the economic efficiency index that increased from 0.295 to 0.616, which confirms a more than twofold increase in the effectiveness of information potential management

Keywords: information potential, digital coherence, digital transformation, economic efficiency, energy enterprise

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1. Introduction

At present, at many power plants, digital technologies are used locally, applying a modular construction principle, which limits the construction of a single comprehensive system for managing the information potential of enterprises. To this end, it is necessary to devise and form a system of criteria and indicators for assessing the level of management of the information potential of an energy enterprise. In connection with the use of information resources in the technological process at energy enterprises (power plants, substations, electrical networks), it is necessary to:

– switch to digital models of information potential management;

– take into account changes in digital data on the parameters of the technological process;

– conduct digital training of operational personnel at the power plant;

– adapt information potential management to external and internal threats.

To take into account the economic and organizational aspects in the activities of energy enterprises, it is necessary to apply a comprehensive approach to assessing the information potential of energy enterprises.

Under conditions of military threats and risks, the issue of optimizing information potential management using information resources becomes critically important. At the same time, in the context of growing volumes of digital resources and growing threats and risks, conventional approaches to assessing information potential management do not make sense.

Thus, the relevance of related research is predetermined by the need to devise a methodology for assessing the effectiveness of managing an enterprise's information potential under conditions of digital coherence.

2. Literature review and problem statement

It is shown in [1] how computer information processing affects the economic results of the institution through improved managerial decision-making, reduced costs, and faster execution of business operations. One of the useful aspects of the study is the emphasis on electronic modernization. The authors believe that the integration of electronic tools is a key factor in the successful management of energy systems. However, the question of how computer information processing affects the economic results of energy enterprises remains unanswered. Possible reasonable factors for this are the lack of a unified approach to the quantitative assessment of information, the difficulty of isolating economic profit from digitalization, the insufficient degree of integration of computerized systems in the institution and the confusing lack of interconnection of digital information.

In study [2], the authors focus on electronic technologies used in production, on the information management system, and on increasing productivity through automation. The implementation of automated process control systems (ACS TP) is a positive aspect that makes it possible to assess the information resource of the enterprise within the framework of the entire electronic structure at the enterprise. However, the authors note the problem of insufficiently developed methods for a comprehensive assessment of the economic impact of information resource management, especially in the case of an electronically conducted institution. This is due to the fact that comprehensive indicators of economic impact still require systematic consideration.

In work [3], electronic technologies and automation are considered as a way to increase the efficiency of management and production operations. The use of ACS is interpreted as one of the ways to design the information structure of an institution, which makes it possible to see its information resource as a component of a holistic electronic environment. However, the authors signal that there are still unresolved issues, in particular, with a consistent assessment of the economic efficiency of information resource management, which is associated with the lack of a comprehensive system analysis. In addition, one can note insufficient research into the issue of information consistency of the administrative, production, and electronic components of an institution, which determines the efficiency of their interaction.

In [4], the strategic importance of merging electronic technologies into classical production schemes is emphasized, considering the importance of information consistency. A favorable aspect of the study is the emphasis on the importance of the electronic structure of the institution. However, the issue of a formalized method for assessing the economic impact of electronic modernizations in information management has not been resolved. The likely reasons are the dominance of qualitative descriptions of operations over quantitative modeling, the lack of a single algorithm that takes into account the relationship between the level of electronic consistency, and the impact of management decisions.

In [5], the effect of information technologies on the economic impact and productivity of institutions is considered, with special emphasis on the interaction of subsystems in the context of electronic consistency. A positive aspect of the study is the emphasis on the importance of merging different subsystems into a single electronic environment, which makes it possible to achieve higher returns for the institution. However, the authors highlight the difficulties of a fragmented approach to assessing the impact of electronic initiatives, which complicates the formation of a holistic picture of the economic feasibility of electronic solutions. This is due to the dominance of technical descriptions and the lack of economic justification of the consequences of electronic modernization, as well as the need to unify indicators for assessing the economic effect of electronic compliance.

Work [6] also focused on the effect of information technologies on the economic impact of institutions, highlighting the importance of combining subsystems to increase productivity in a holistic electronic environment. The main advantage of the study is the recognition of the need to coordinate electronic solutions within the institution to ensure optimal economic results. However, despite this, the questions of a complete analysis of the economic feasibility of such solutions remain unanswered. The reason is the heterogeneity of approaches to assessing the impact and the lack of common methods for determining the economic effect of electronic integrity, which narrows the possibilities of a comprehensive assessment of the economic benefits of electronic innovations.

In [7], the attention is paid to the need for e-leadership to achieve competitiveness by merging electronic tools in the business model. A favorable factor for the study is the importance of e-management capabilities in constructing flexible governance models. However, the issue of systematically assessing the impact of e-leadership on the return on management of information resources of institutions has not been resolved. The likely reason is that emphasis is mostly on general strategies for electronic modernization without a detailed analysis of the economic consequences of electronic changes at the level of individual subsystems.

In [8], the use of electronic twins in production systems is justified in order to increase the return on management decisions. A positive factor of the study is the feasibility of using virtual models for scenario modeling and cost reduction. However, the issue of merging electronic twins into a complex system for assessing the economic return on management of information resources has not been resolved. These reasons may relate to the narrow focus of the study on the technological side of electronic twins without taking into account the consistency with other information components of the institution. In addition, no technique for numerically assessing the economic impact of implementing electronic twins within the information resource of the institution has been proposed; there is no connection with the indicators of electronic consistency.

Work [9] considers the impact of intelligent products and connected systems on changes in the competitive environment. A positive aspect of the study is the new opportunities for electronic modernization through the collection and analysis of information under the reality mode. However, the issues of merging intelligent products into the system for assessing the impact of managing the information resource of energy enterprises remain unanswered. The likely reasons are focusing on strategic advantages without proper analysis of the economic consequences for the information infrastructure of the institution. In addition, there is no model for assessing the economic impact of implementing solutions in the context of integrated information resource management; the aspects of electronic consistency between technological, analytical, and organizational subsystems are not taken into account.

In [10], attention is on the systemic fusion of electronic technologies, cyber-physical systems, and automated production control systems. A positive aspect of the study is the relationship between IT solutions and production subsystems, which contributes to the formation of a cellular electronic environment. However, the issues of comprehensive assessment of the impact of electronic fusion at energy institutions, in particular regarding the relationship between technological modernization, information compliance, and economic efficiency, have remained unresolved. The likely reasons are the lack of mechanisms for measuring the economic effect of such integration and the lack of indicators that take into account the compliance of information, management and technological components.

Electronic modernization and informatization were considered: in [11] – in relation to the structure of the institution's information resource; [12] – in the context of electronic strategies of energy companies; [13] – in relation to the economic aspects of the implementation of ACS TP and information management. A remarkable feature is the practical orientation of studies. The proposed solutions are focused on optimizing production and management operations, which is important for the energy sector. However, the issue of devising unified approaches to numerical assessment of the impact of electronic modernization of the information resource at energy enterprises, taking into account the industry specificity and risks of functioning in an unstable energy market, has not been resolved. The likely reason is insufficient adaptability to the specificity of energy institutions. In addition, some elements of electronic modernization are presented universally without taking into account the characteristics of thermal power plants, such as interaction with APCS systems, technological inertia or specific risks of the energy market.

Based on our review of the literature [1–13], the following unresolved problems of assessing the economic efficiency of managing the information potential of energy enterprises in the context of digital transformation can be identified:

– lack of integrated models of economic efficiency of information potential management, which take into account both direct (cost reduction) and indirect effects (reduction of downtime, increased reliability of management decisions, avoidance of information losses);

– insufficient development of methods for controlling the economic efficiency of digital changes, as well as the lack of criteria that would make it possible to distinguish between effective and ineffective digital initiatives at the level of individual elements of the enterprise's information infrastructure;

– ignoring the cost of transformational changes and the investment payback level, which complicates decision-making on the feasibility of digital projects;

– economic efficiency is often considered as a static indicator, without taking into account the costs of implementation, personnel training, and modernization of information technologies (IT);

– lack of differentiated models for assessing economic efficiency depending on the level of digital maturity of the enterprise, its technological cycle or scale of activity;

– universal approaches do not take into account that the effectiveness of digital integration processes is a variable value that significantly depends on the current level of technological, organizational and information development of the energy enterprise;

– weak integration of information and analytical systems into the economic planning system, which makes it impossible to quickly adapt management decisions to changes in the external or internal environment;

– there is a gap between digital data and the system of economic management of the information potential of the energy enterprise;

– the relationship between the degree of coherence of information flows and the financial results of the enterprise remains at the level of a hypothesis, without a confirmed empirical model;

– lack of systematic adaptation of global models of digital transformation to the conditions of the Ukrainian energy sector, where efficiency is affected by factors of external instability: energy market, currency risks, regulatory uncertainty, infrastructure restrictions.

Thus, the problem of quantitative assessment of the economic efficiency of information potential management of energy enterprises, taking into account the level of digital coherence, is multifaceted and requires a comprehensive approach to its solution. To achieve sustainability and competitiveness of enterprises, it is necessary to take into account not only economic indicators but also environmental and social consequences, as well as improve organizational structures and methodologies for managing the information potential of energy enterprises. This will allow for a more in-depth and objective assessment of economic efficiency, taking into account the level of digital coherence.

3. The study materials and methods

The purpose of our study is to devise a methodology for assessing the economic efficiency of managing the information potential of energy enterprises, taking into account the factors of digital coherence, which allows for the formation of effective management decisions in the process of digital transformation of energy enterprises.

To achieve this goal, the following tasks were set:

– to determine the stages of a comprehensive methodology for assessing the economic efficiency of managing the information potential of an energy enterprise based on determining the criteria and indicators for assessing economic efficiency after the implementation of investments;

– to examine the results based on the practical application of the proposed methodology for assessing the economic efficiency of managing the information potential of an energy enterprise using the example of an investment project regarding the implementation of a digital twin as part of the ACS TP of the power unit at the Zaporizhzhia Power Plant.

4. The study materials and methods

The object of our study is the process of assessing the economic efficiency of the implementation of an investment project aimed at managing the information potential of an energy enterprise, taking into account digital coherence factors.

The hypothesis of the study assumes that the integration of digital coherence factors (level of digital maturity, stability of digital infrastructure) into the assessment of the economic efficiency of investment projects for managing information potential makes it possible to achieve reliability and validity of the results. This, in turn, contributes to making effective management decisions, increasing the effectiveness of investment activities and accelerating the digital transformation of the enterprise.

When implementing the methodology for assessing economic efficiency, a number of assumptions of the study were taken into account:

– stability of technological infrastructure – it is assumed that during the period under review, the basic digital platforms of the enterprise did not undergo any fundamental changes; this simplifies the preparatory and diagnostic stage of the analysis, but may underestimate the impact of modernizations;

– linear dependence between the level of digital coherence and economic effect – adopted for the stage of identification of components of information potential, which makes it possible to simplify the mathematical model, but ignores possible effects of threshold values;

– homogeneity of equipment operating conditions – assumed for the stage of determination of economic efficiency indicators in order to avoid the influence of specific factors (energy load) on economic efficiency.

Thus, the study makes it possible to obtain a generalized and suitable for strategic planning index of economic efficiency but requires additional checks and corrections when used for short-term forecasts or comparisons between different enterprises.

Conventional methods of information potential management have limitations [14, 15] such as a low speed of information processing; lack of integrated analysis in real time; high probability of personnel errors; insufficient consistency between information systems [16].

The implementation of a digital twin makes it possible [17] to combine data from all information subsystems into a single digital coherent model; to perform analytics and forecasting of equipment conditions; to optimize maintenance costs; to increase the accuracy of management decisions [18].

5. Results of devising a comprehensive methodology for assessing the economic efficiency of managing the information potential of an energy enterprise

5. 1. Defining the stages in a methodology for assessing the economic efficiency of managing the information potential of an energy enterprise

Devising a comprehensive methodology for assessing the economic efficiency of managing the information potential of an energy enterprise under the conditions of digital coherence includes several stages (Fig. 1), each of which has its specific characteristics:

1. Stage No. 1 – preparatory and diagnostic, which determines:

– identification of the components of the information potential: a systematic analysis of the available information resources, the level of digital competencies of personnel, as well as the availability of digital development strategies is carried out;

– formulation of the goals of information potential management in accordance with the general strategy of the enterprise (increasing productivity, reducing accidents, ensuring cyber resilience, etc.);

– initial diagnostics of digital coherence by assessing the consistency between the technical, organizational and analytical components;

– formation of a list of input indicators that are selected as quantitative (average transaction time) and qualitative (digital maturity indices, readiness for change);

– organization of a primary data collection system based on the development of a survey plan, integrations for automated collection of technical information.

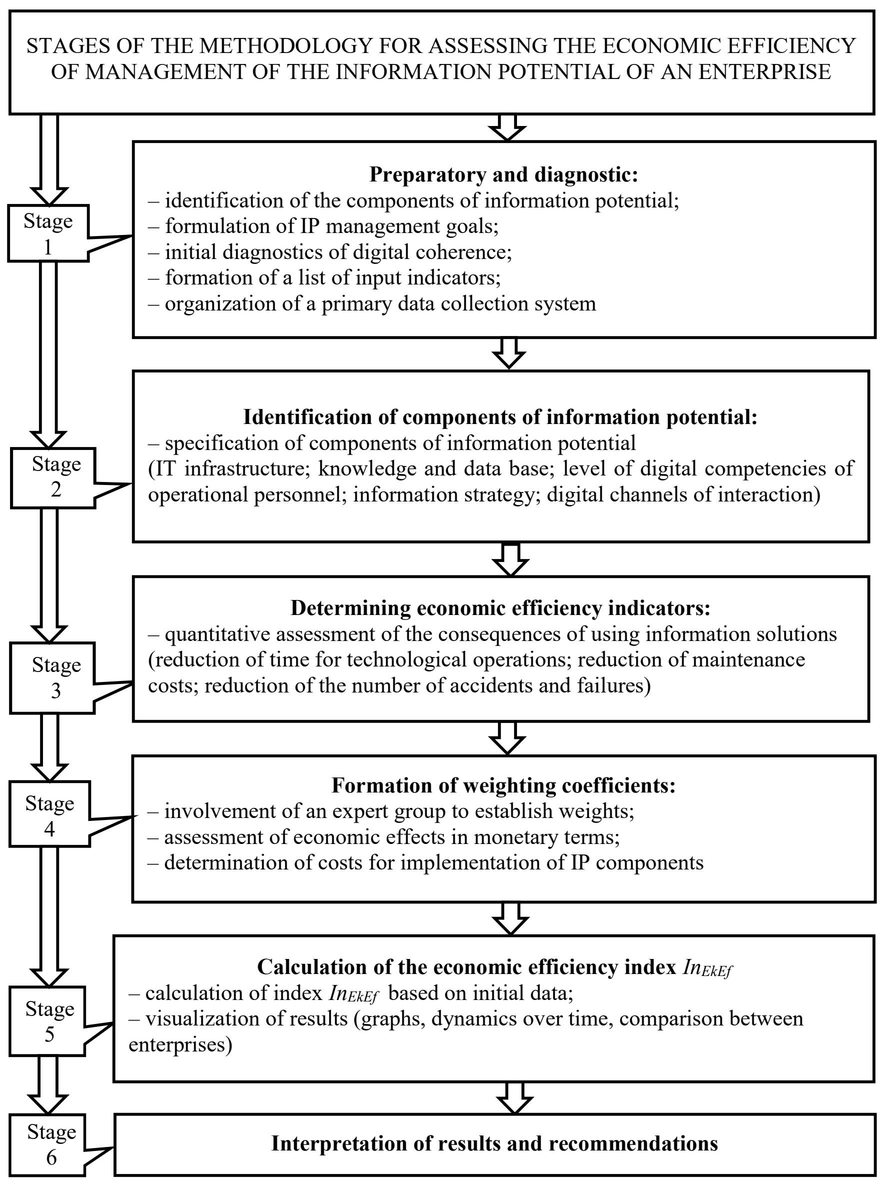

Fig. 1. Flowchart of stages in the methodology for assessing the economic efficiency of managing the information potential of an energy enterprise

At this stage, the information potential is considered as system (F_{inf}) of (k) components (1)

$$F_{inf}(k) = (R_{inf}, T_{inf}, C_{dig}, H_{inf}, S_{inf} \ldots), \tag{1}$$

where R_{inf} – information resources;

T_{inf} – IT infrastructure;

C_{dig} – digital competence of personnel;

H_{inf} – data processing and storage systems;

S_{inf} – communication and data transmission channels.

2. Stage No. 2 – identification of components of information potential, on the basis of which the key components of IP are specified on the basis of the previous stage:

– IT infrastructure (servers, networks, cloud services);

– knowledge and data base (volumes, systematization, relevance);

– level of digital competencies of personnel (evaluation results);

– information strategy (availability, goals, compliance with business strategy);

– digital interaction channels (automated control system of APCS, etc.).

This stage reflects the degree of availability, maturity, and balance of the main components of the information potential at the energy enterprise. Its main function is to quantitatively assess the completeness of the formation of the information potential as a system, that is, how well the key components are developed.

3. Stage No. 3 – determination of economic efficiency indicators from information potential management, which includes a quantitative assessment of the consequences of using information solutions:

– reduction of the time of technological operations;

– reduction of maintenance costs;

– reduction of accidents and failures;

– improvement of quality of management decisions;

– increase of productivity of IT personnel.

At this stage it is proposed to calculate the change of efficiency as a result of implementation of digital solutions and to obtain direct economic effect after implementation of digital technologies on management of IP according to expression (2)

$$E_{EE} = (P_{PB_1} - P_{PB_0}) - (C_{V_1} - C_{V_0}), \tag{2}$$

where E_{EE} is the economic effect indicator after the implementation of digital technologies for IP management;

P_{PB1} is the profit after the implementation of digital technologies for IP management;

P_{PB0} is the profit before the implementation of digital technologies for IP management;

C_{V1} is the cost after the implementation of digital technologies for IP management;

C_{V0} is the cost before the implementation of digital technologies for IP management.

The economic effect of increasing the productivity of information activities is an indicator that reflects the impact of increasing the efficiency of processing, creating or using information on the overall economic result of the enterprise as a result of implementing information potential management measures.

A positive economic effect from improved productivity of information activities is observed when $E_{EE} > 0$. The larger the volume of high-quality information and the higher the digital efficiency, the higher the economic effect. Also, the shorter the average processing time, the higher the economic effect.

4. Stage No. 4 – formation of weight coefficients (ω_i) for the correct calculation of the economic efficiency index, for which it is necessary:

– to involve an expert group to establish weights;

– to assess economic effects in monetary or relative terms;

– to determine the costs of implementing the components of information potential.

Formation of weight coefficients (ω_i) is a critical stage for ensuring the objectivity of a comprehensive assessment of economic efficiency. The involvement of experts makes it possible to take into account strategic and technological priorities, while economic standardization supports decisions with substantiated financial data.

To build a system of weight coefficients (ω_i), which determine the importance of each measure, component or direction of investment in information potential management for further objective calculation of the integral index of economic efficiency.

It is proposed to calculate from expression (3) the weight coefficient (ω_i) through the normalization of expert assessment

$$\omega_i = \frac{S_i}{\sum_{j=1}^{n} S_j}, \tag{3}$$

where ω_i is the weighting coefficient of the i-th economic efficiency indicator;

S_i is the score of the expert assessment of the significance of the i-th measure;

S_j is the expert assessment of the significance of the j-th component of the information potential (or its management measure), which is given by an expert or a group of experts.

Each component j (for example, IT infrastructure, digital competence of personnel, etc.) receives a certain quantitative assessment of significance (S_j), which shows how important this component is for achieving overall economic efficiency. Such assessments can be in points, for example, on a scale from 0 to 1. After each component has received its score (S_j), all assessments are summed up, and each weight ω_i is also determined as a share of the assessment (S_i) to the total sum of assessments. Therefore, S_j is a quantitative assessment of the significance of each component (given by the expert), and not some variable from the formula – this is the input value required for calculating the weighting coefficients (ω_i). In this case, equality (4) must be fulfilled – the sum of all weight coefficients (ω_i) is equal to unity

$$\sum_{j=1}^{n} \omega_i = 1, \tag{4}$$

This means that all indicators of economic efficiency when weighed will be comparable, regardless of their number or absolute values.

5. Stage No. 5 – calculation of the economic efficiency index of information potential management of an energy enterprise.

To do this, the following is performed:

– calculation of the economic efficiency index based on initial data;

– visualization of results (graphs, dynamics over time).

The economic efficiency of information potential is not the cost of digitalization, but the benefits that it brings to the enterprise through increased efficiency, profitability and sustainability.

Possible integration with indicators of economic efficiency of the energy enterprise system is considered, in particular through indicators: assessment of the economic effect of preventing downtime (In_{SLA}); return on investment (In_{ROI}); digital coherence index (In_{zk}); personnel productivity (In_{PI}).

Thus, the economic efficiency of information potential management is a conditional aggregated index based on normalized values of In_{SLA}; In_{ROI}; In_{zk}; In_{PI}.

It is proposed to calculate the economic efficiency index of information potential management (In_{EkEf}) based on the normalized values of the indicators: In_{SLA}; In_{ROI}; In_{zk}; In_{PI}, according to expression (5)

$$In_{EkEf} = \omega_1 \cdot {}^2n_{SLA} + \omega_2 \cdot {}^2n_{ROI} + \omega_3 \cdot {}^2n_{zk} + \omega_4 \cdot {}^2n_{PI}, \qquad (5)$$

where In_{EkEf} is the index of economic efficiency of information potential management;

In_{SLA} is the indicator of the assessment of the economic effect of preventing downtime, failures and accidents;

In_{ROI} is the indicator of return on investment;

In_{zk} is the index of digital coherence;

In_{PI} is the indicator of personnel productivity;

ω_1, ω_2, ω_3, ω_4 – weighting coefficient for the index of indicators In_{SLA}; In_{ROI}; In_{zk}; In_{PI}, respectively.

The indicator of the assessment of the economic effect of preventing downtime, failures and accidents (In_{SLA}) determines the standardized parameters of the quality of IT services (availability, response time, recovery time, etc.).

In the context of the information potential of an energy enterprise:

– high InSLA indicators indicate the stability of the digital infrastructure, which contributes to the continuity of the technological process and the reduction of operating costs;

– the InSLA indicator is used to assess the economic effect of preventing downtime, failures and accidents and is calculated from expression (6)

$$In_{SLA} = \frac{\Delta T_{zps}}{T_g} \cdot 100\%, \qquad (6)$$

where In_{SLA} – indicator for assessing the economic effect of preventing downtime, failures and accidents;

ΔT_{zps} – reduction in system downtime (shows how many hours of unplanned downtime are reduced after the implementation of measures, which can be achieved through forecasting breakdowns, automatic control or optimization of equipment operation);

T_g – total system downtime (hours).

Thus, the In_{SLA} indicator makes it possible to numerically assess the benefit of preventing accidents and failures and is used as an important indicator of the effectiveness of implementing digital technologies or management solutions at power plants.

Return on investment (In_{ROI}) shows what profit or economic effect is obtained from investments in IT solutions or a system for managing the information potential of an energy enterprise and is calculated from expression (7)

$$In_{ROI} = \frac{EE_{year} - Inv}{Inv} \cdot 100\%, \qquad (7)$$

where In_{ROI} is the profitability index (%);

EE_{year} is the economic effect of reducing downtime, failures, accidents;

Inv is the total cost of implementing and maintaining solutions (investments are the total costs of purchasing, installing, training personnel, and maintaining an IT system) for managing information potential.

An explanation of the economic essence of the profitability of investments in obtaining the economic effect of systems for managing the information potential of an energy enterprise is given:

– if $In_{ROI} > 0\%$, the investment pays off and is profitable;

– if $In_{ROI} < 0\%$, the investment is unprofitable (costs exceed the effect);

– if $In_{ROI} = 100\%$, this means that the effect is twice as high as the costs.

Approximate standards for the profitability index in the electric power industry:

– $In_{ROI} \geq 20$–25% is a good indicator for long-term investments in IT/IP in the energy sector;

– $In_{ROI} \geq 50\%$ – highly profitable project;

– $In_{ROI} < 0\%$ – requires strategy revision.

The profitability indicator (In_{ROI}) is a universal and understandable indicator for assessing the success of information potential management, which makes it possible to you to combine financial results with technological efforts. The profitability indicator (In_{ROI}) should be mandatory in the system for evaluating digital initiatives at energy enterprises. In addition, this indicator makes it possible to reasonably assess how profitable the implementation of digital tools was in information potential management. The profitability indicator (In_{ROI}) combines technical and economic aspects and is a key indicator of the financial efficiency of any digital transformation.

Thus, the profitability indicator (In_{ROI}) is an indicator of the economic feasibility of digital investments that makes it possible:

– to assess the effectiveness of specific projects (automation, modernization);

– to compare efficiency between enterprises;

– to form investment priorities.

The calculation of the digital coherence index (In_{zk}) is based on the aggregation of partial digital coherence indices taking into account their weighting according to expression (8)

$$In_{zk} = \omega_1 \cdot In_{IS} + \omega_2 \cdot In_{TC} + \omega_3 \cdot In_{AC} + \omega_4 \cdot In_{CS}, \qquad (8)$$

where In_{zk} – digital coherence index;

In_{IS} – strategic coherence index;

In_{TC} – technological compatibility index;

In_{TC} – analytical integrity index;

In_{CS} – cyber resilience index;

ω_1, ω_2, ω_3, ω_4 – weighting coefficient for the index of indicators In_{IS}; In_{TC}; In_{AC}; In_{CS}, respectively.

Personnel productivity indicator under digital coherence conditions (In_{PI}) reflects the efficiency of using human potential in the information environment of an energy enterprise, taking into account access to data, digital tools, and organizational integration (9)

$$In_{PI} = \frac{Q_{inf} \cdot E_{dig}}{T_{avg} \cdot N}, \qquad (9)$$

where In_{PI} – personnel productivity indicator in digital coherence conditions;

Q_{inf} – volume of processed or created qualitative information for the period (expert quantitative assessment of information processed by an employee for a certain time);

$E_{dig} \in [0;1]$ – digital efficiency coefficient – a normalized index of digital transformation, which by expert method reflects the level of automation, digital maturity, use of ICT in a specific unit or enterprise as a whole;

T_{avg} – average time spent on one information operation (hours/day), which reflects the efficiency and speed of information processing by personnel (the smaller the T_{avg} value, the faster one operation is performed);

N – number of employees who participated in information activities.

Thus, the stages of a comprehensive methodology for assessing the economic efficiency of managing the information potential of an energy enterprise have been defined.

5. 2. Testing the proposed methodology for assessing the economic efficiency of managing the information potential of energy enterprises

The proposed methodology for assessing the economic efficiency of managing the information potential of energy enterprises under conditions of digital coherence was tested using an example of Zaporizhzhia Power Plant. Based on formulas (3) to (9), calculations of key indicators for assessing the economic efficiency of managing the information potential were carried out, with realistic input initial data on Zaporizhzhia Power Plant. The initial data before and after the implementation of the digital twin for calculating the economic efficiency of managing the information potential of ZPP (2021) are given in Table 1.

According to formula (6) and initial data (Table 1), the indicator for assessing the economic efficiency of preventing downtime, failures, and accidents was calculated (Table 2):

– before implementing the digital twin: there is no economic effect from preventing downtime, failures, and accidents, losses are equal to the baseline: $In_{SLA} = 0$;

– after implementing the digital twin: $In_{SLA} \approx 33\%$).

The value of the accident indicator of the assessment of the economic effect from preventing downtime, failures, and accidents ($In_{SLA} = 33\%$) after the implementation of the digital twin at the Zaporizhzhia power plant made it possible:

– to reduce equipment downtime by 33.3%;

– to reduce annual losses by 20 million UAH;

– to increase the economic efficiency of the power unit by a third compared to the baseline.

In accordance with formula (7) and the initial data (Table 1), the return on investment indicator was calculated (Table 2):

– before implementing the digital twin: $In_{ROI} = 0$;

– after implementing the digital twin: $In_{ROI} \approx 67\%$.

Before implementing the digital twin, the economic effect was equal to the amount of investment, the profitability was 0%, that is, the invested funds did not bring additional profit. The value of $In_{ROI} \approx 67\%$ indicates that the economic effect is twice as high as the costs, and the investment is highly profitable.

The implementation of the information potential management system and the digital twin in the ACS TP of ZPP power unit made it possible:

– to achieve an economic effect of 20 million UAH per year,

– with investments of 12 million UAH, it ensured profitability of ≈67%, which is a highly profitable and strategically appropriate solution for the further development of the enterprise's information infrastructure.

According to formula (8) and the initial data (Table 1), the digital coherence index indicator (Table 2) was calculated:

– before implementing the digital twin $In^1_{ZK} = 0.581$;

– after implementing the digital twin: $In^2_{ZK} = 0.744$.

Table 1

Initial data for calculating indicators of economic efficiency of information potential management before and after the implementation of a digital twin in the process control system of the power unit of Zaporizhia Power Plant

Indicator	Indicator value	
	Before DT	After DT
T_{zps} – system downtime (hours)	120	80
ΔT_{zps} – loss reduction (%)	–	40
C_{var} – cost of one hour of downtime of the power plant (UAH/hour);	500000	500000
EE_{pik} – annual savings after implementing a digital twin (mln. UAH)	–	20
$\sum In$ – total investments in the creation, implementation and maintenance of a digital twin (mln. UAH)	–	12
Q_{inf} – volume of processed or created qualitative information (units)	1000	1200
V_{inf} – cost of a unit of processed information (UAH)	16	19
E_{deg} – digital efficiency ratio: automation level (0 ÷ 1)	0.50	0.75
T_{avg} – average time spent on one information operation (hours)	0.6	0.5
N_{ω} – average number of employees involved in information processing (persons)	8	8
In_{v} – investments for the implementation of a digital twin), UAH million	–	1.2
In_{IS} – strategic coherence index (0 ÷ 1)	0.62	0.78
In_{TC} – technological compatibility index (0 ÷ 1)	0.60	0.72
In_{AC} – analytical integrity index (0 ÷ 1)	0.58	0.71
In_{CS} – cyber resilience index (0 ÷ 1)	0.50	0.65
$\omega_1(In_{IS})$ – weighting factor for In_{IC}	0.30	0.30
$\omega_2(In_{TS})$ – weighting factor for In_{TC}	0.25	0.25
$\omega_3(In_{AS})$ – weighting factor for In_{AC}	0.25	0.25
$\omega_4(In_{CS})$ – weighting factor for In_{CS}	0.20	0.20

Note: USD 1 is equivalent to UAH 42 as of 10/10/2025.

The $In^2_{ZK} = 0.744$ value shows a sufficiently high level of digital coherence of the Zaporizhzhia Power Plant after implementing the digital twin (for comparison: $In_{ZK} < 0.5$ – low level of digital coherence; $0.5 \leq In_{ZK} < 0.7$ – medium level; $In_{ZK} \geq 0.7$ – high level.

According to formula (9) and initial data (Table 1), the personnel productivity indicator was calculated under digital coherence conditions (Table 2):

– before implementing the digital twin: $In_{1PI} = 104.17$;

– after implementing the digital twin: $In_{2PI} = 225$;

– relative productivity growth: $\Delta I_{2PI} = 116\%$.

The implementation of the digital twin doubled personnel productivity:

– before implementing the digital twin – 104 units/hour/employee;

– after the implementation – 225 units/hour/employee;

– the growth was 116%.

This reflects the effectiveness of using digital tools, automation, and organizational integration. The In_{PI} indicator makes it possible to quantitatively assess the benefits of digital transformation for human potential.

To determine a comprehensive assessment of the level of economic efficiency of managing the information potential of the energy enterprise of ZPP, it is advisable to use the economic efficiency index (In_{EkEf}), which takes into account the influence of four key normalized indicators according to expression (6) to (9).

In accordance with formula (5) and the data of the calculated economic indicators In_{SLA}; In_{ROI}; In_{ZK}; InP_I, the economic efficiency index (In_{EkEf}) was calculated before and after implementing the digital twin in the ACS TP of ZPP power unit. The results of the calculations of the economic efficiency index of managing the information potential before and after implementing the digital twin in the ACS TP of ZPP power unit for 2021 are given in Table 2.

A comparative analysis of the results of calculating the economic efficiency indicators of information potential management (Table 2) revealed a significant increase in all indicators after the implementation of a digital twin in the ACS TP of the power unit of ZPP power plant:

– the accident rate was reduced by 33%;

– the return on investment reached 67%;

– digital coherence increased from an average (0.58) to a high level (0.74);

– personnel productivity increased by 116%;

– the economic efficiency index (InEkEf) increased from 0.295 to 0.616, which confirms a more than twofold increase in the effectiveness of information potential management.

In general, the results indicate the achievement of high economic efficiency and digital consistency of processes after implementing digital twin. These results confirm the hypothesis that taking into account digital coherence factors when assessing investment projects provides greater reliability and validity of management decisions.

Table 2

Results of calculating economic efficiency indicators before and after the implementation of a digital twin in the ACS TP of ZPP

No.	Indicator	Result		Change, (increase) %
		Before DT	After DT	
1	In_{SLA} – economic efficiency indicator from preventing downtime, failures and accidents, %	0%	33.3%	+ 33.3
2	In_{ROI} – return on investment in the IP management system, %	0%	≈ 67%	+ 67
3	In_{ZK} – digital coherence index, conventional units	0.581	0.744	+ 28.0
4	In_{PI} – personnel productivity indicator in digital coherence conditions, conventional units	104.17	225	+ 116
5	In_{EkEf} – economic efficiency index of information potential management, conventional units	0.295	0.616	+ 109

Based on the data in Table 2, a chart (Fig. 2) was constructed, which depicts an increase in economic efficiency indicators after implementing digital twin at the energy enterprise ZPP. This chart reflects the change in percentage (%), which characterizes the increase in each indicator after implementing digital twin in the ACS TP of ZPP power unit relative to the baseline level ("before implementation"). The chart (Fig. 2) shows that:

– the largest increase is the information process productivity index In_{PI} = 116%, which indicates a significant increase in the speed, consistency, and reliability of information processing after implementing digital twin;

– the economic efficiency index (In_{EkEf}) increased by 109%, which confirms the overall improvement of the economic results of the energy enterprise;

– the return on investment index (In_{ROI}) increased by 67%, which indicates the effective use of resources invested in digitalization;

– the service level index (In_{SLA}) increased by 33.3%, that is, the stability and quality of technological processes increased;

– the smallest increase was recorded for the In_{ZK} indicator (28%), which may indicate the gradual nature of cost savings that appear over time.

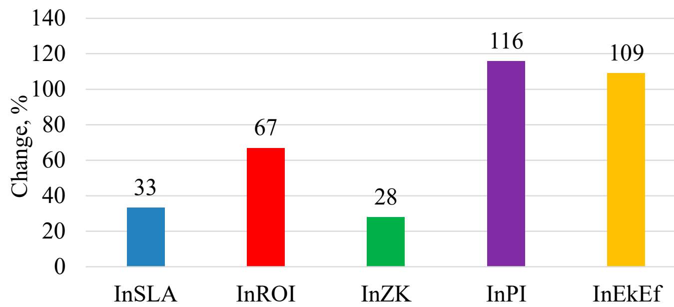

Fig. 2. Chart of the increase in economic efficiency indicators after the implementation of a digital twin in automated process control systems of the power unit at Zaporizhzhia Power Plant

Thus, the implementation of the digital twin ensured a comprehensive increase in the economic efficiency of the power plant, in particular by optimizing the management of information flows, increasing the transparency of processes and timely diagnostics of deviations.

Thus, our results indicate that the implementation of the digital twin contributed to a significant increase in the economic efficiency of managing the information potential of the power plant. The greatest growth was recorded in the indicators of the productivity of information processes and the integral index of economic efficiency, which confirms the synergistic effect of digitalization. The improvement of the indicators of the profitability of investments and the level of service demonstrates an increase in the efficiency of resource use and the stability of technological processes. Thus, the digital twin has become an effective tool for increasing the effectiveness of management decisions and the long-term competitiveness of the energy enterprise.

Among the recommendations for effective management of the information potential of energy enterprises under the conditions of digital coherence, the following can be noted:

– regarding increasing the adaptability of ACS TP: implementation based on the implementation of digital twins;

– ensuring digital coherence by integrating IT infrastructure, data, analytical models and personnel into a single information environment;

– monitoring the effectiveness of digital transformations by implementing a cost-effectiveness index tracking system;

– reducing dependence on external influences by implementing elements of cyber resilience and autonomous management of information flows.

6. Results of devising a comprehensive methodology for assessing the level of economic efficiency of information potential management: discussion and summary

A comprehensive methodology for assessing the economic efficiency of information potential management of an energy enterprise under the conditions of digital coherence has been proposed, which has shown high sensitivity to changes in the structure of information potential management of energy enterprises.

The proposed methodology (Fig. 1) is an important tool for managing the information potential of energy enterprises, but it is shown that its effectiveness depends on the possibility of using it as a diagnostic tool for predicting the effectiveness of digital coherence.

Unlike the methodologies reported in [19–21], in which the assessment of the economic efficiency of digitalization is carried out mainly through aggregated financial indicators, without taking into account the structural complexity of the information environment, the proposed methodology makes it possible to us to define the stages:

– taking into account the multidimensional nature of the enterprise's information potential;

– key resources, processes, and components that form the information potential of the enterprise, including IT infrastructure, personnel, data transmission channels, and information quality;

– indicators of economic efficiency and digital efficiency;

– quantitative assessment of the impact of digital technologies (automation, digital maturity) on the productivity of information activities and economic results of the enterprise;

– priority and significance of various components of information potential, ensuring correct aggregation of indicators into an economic efficiency index.

It is these stages, defined within the proposed methodology, that make it possible to move from a superficial financial assessment to a deep analysis of the structural complexity of the information environment of an energy enterprise. This provides an assessment of information potential – as a system that includes digital infrastructure and the level of digital coherence.

The result of forming an economic efficiency index taking into account digital coherence – becomes possible due to a phased analysis of the priority of the components of information potential and their impact on productivity and economic results. This approach makes it possible to assess the current state and predict the effectiveness of digital initiatives, identify weaknesses in management, and form substantiated recommendations for strategic development.

The proposed methodology for assessing the economic efficiency of information potential management was tested based on the analysis of actual data on the Zaporizhzhia Power Plant in 2021. The results of testing the methodology allowed us to determine the change in the economic efficiency index, which was calculated taking into account the implementation of a digital twin, improving the quality of information, digital efficiency of personnel, and reducing time spent on information operations. The methodology allowed us to determine the real economic efficiency of implementing a digital twin, as well as to assess the impact of digital coherence – that is, how well the digital, technological, managerial, and information components of the enterprise work.

According to the results of testing the methodology, the dynamics of the economic efficiency index were determined. The data in Table 2 indicate the effectiveness of the proposed assessment methodology – it makes it possible to identify weaknesses in the management of information potential and shows the effectiveness of implemented digital initiatives.

A direct relationship between the level of digital maturity of information environment management and the overall efficiency of the enterprise has been shown. This dependence confirms the correctness of the applied methodology for assessing the economic efficiency of IP management, the numerical results of which are given in Table 2.

An analysis of the increase in economic efficiency indicators after the implementation of a digital twin at the energy enterprise ZPP (Fig. 2) was conducted:

– the greatest increase was demonstrated by the information process productivity index In_{PI} = 116%, which indicates a significant increase in the speed, consistency and reliability of information processing after implementing digital twin;

– the economic efficiency index (In_{EkEf}) increased by 109%, which confirms the overall improvement of the economic results of the energy enterprise;

– the return on investment index (In_{ROI}) increased by 67%, which indicates the effective use of resources invested in digitalization;

– the service level index (In_{SLA}) increased by 33.3%, that is, the stability and quality of technological processes increased;

– the smallest increase was recorded for the In_{ZK} indicator (28%), which may indicate the gradual nature of cost savings that appear over time.

Our methodology assumes the availability of structured and complete data on the information potential of the enterprise, including indicators of IT infrastructure, digital maturity of personnel, and the quality of information processes, which is not always available in practice. The effectiveness of the assessment significantly depends on the accuracy of determining the weighting coefficients that aggregate the indicators into an index of economic efficiency, and errors in their calculation can distort the results. In addition, the methodology is focused mainly on enterprises that are at the stage of active digital transformation and may be less effective for organizations with a low level of digital maturity or a conservative management structure.

During the implementation of the methodology for assessing economic efficiency, a number of shortcomings were identified that can be eliminated in the process of further improving the model. The development of stages for assessing the economic efficiency of managing the information potential of an investment project is a complex systemic process that requires flexibility and adaptation to the specificity of a particular enterprise. Therefore, it is necessary to refine the mechanism for taking into account changes in the digital maturity of the enterprise and ensure a more accurate correction of economic efficiency indices in dynamics, in particular under conditions of rapid changes in the external environment.

Further development of this methodology can be aimed at automating the assessment process through a digital platform for monitoring information potential, as well as expanding its application in order to form a single standard for assessing digital efficiency.

7. Conclusions

1. We have shown that the development of stages in the methodology for assessing the economic efficiency of information potential management of an investment project is a complex systemic process. This involves a phased determination of the structure of information potential, assessment of the digital maturity of the enterprise, calculation of partial and integral indices of economic efficiency. Each stage plays

an important role in forming a comprehensive picture of the level of effectiveness of information potential management of energy enterprises. The main stages of the economic efficiency assessment process have made it possible to determine the criteria and indicators for assessing economic efficiency; to perform calculations of key indicators (In_{SLA}, In_{ROI}, In_{ZK}, In_{PI}); to form an index of economic efficiency of information potential management (In_{EkEf}). That has made it possible to objectively assess the investment project after the implementation of a digital twin in the ACS TP of the power unit at Zaporizhzhia Power Plant. The stages defined provide not only the systematization of approaches to measuring efficiency but also form an information basis for making management decisions on further improving the digital infrastructure of the enterprise.

2. The proposed methodology is practically applicable for industrial energy facilities that are in the process of digital transformation. Its testing on the example of Zaporizhzhia TPP showed high sensitivity to changes in the structure of information potential and the level of digital coherence. The implementation of a digital twin and an information potential management system at ZPP doubled the economic effect and provided a highly profitable investment ($In_{ROI} \approx 67\%$), confirming the effectiveness of the digital transformation of ZPP enterprise. The results obtained show that the economic efficiency index (In_{EkEf}) is reliably correlated with actual indicators of productivity, economic efficiency and reliability of the ZPP power unit. The implementation of the methodology makes it possible to to identify periods of peak efficiency of the use of information potential; to identify risk areas in the management of information flows; to optimize the structure of information potential to achieve maximum synergy between the technical and personnel components.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors declare the use of the AI tool: ChatGPT model (OpenAI GPT-5, version 2025), number 5.0.1.

The AI tool was used in the “Introduction” section and in the “Literary data analysis and problem statement” section.

The AI tool was used for editing and grammar checking.

The results provided by the AI tool were verified by manual testing on real texts of the authors’ scientific publications.

The results provided by the AI tool reduced the impact of human grammatical errors when formulating conclusions for the study.

Authors’ contributions

Viktoriia Prokhorova: scientific guidance, conceptualization, project administration, text editing; **Oleksandr Budanov**: methodology development, research, validation, interpretation of results; **Pavlo Budanov**: data processing, visualization of writing the initial version of the text; **Anatoliy Babichev**: attracting funding, providing resources; **Krystyna Slastianykova**: software, formal analysis.

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